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Effects of Environmental Contaminants on Reptiles: A Review

By

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Abstract

The literature relating to the effects of environmental contaminants on reptiles is reviewed and certain generalizations based on studies of other kinds of vertebrates are presented. Reports of reptilian mortality from pesticide applications are numerous enough to establish the sensitivity of reptiles to these materials. Reports of residue analyses demonstrate the ability of reptiles to accumulate various contaminants, but the significance of the residues to reptilian populations is unknown. A few authors have reported the distribution of residues in reptilian tissues; others have investigated uptake or loss rates. Physiological studies have shown that organochlorines may inhibit enzymes involved in active transport and have correlated the activity of potential detoxifying enzymes with residue levels. There is some suggestion that pesticide residues may interfere with reproduction in oviparous snakes. Needs for future research are discussed.

Our knowledge of the effects of pesticides and other environmental contaminants on reptiles is severely limited. The literature consists of reports of reptilian mortality in field applications, reports of residue analyses, and a mere handful of studies designed specifically to investigate reptilian responses to contaminants. Not only is the available information fragmentary, but it relies on a confusing array of test conditions, analytical procedures, and methods of reporting results. Opportunities for misinterpretation are many; despite nearly 40 years of study we have only scant knowledge of which chemicals may be particularly hazardous to reptiles. Further, we can only speculate on the significance of residues of environmental contaminants found in tissues of reptiles. It is the purpose of the present review to summarize the available literature in a way that will permit future studies to be more responsive to the many questions that remain.

For guidance one may turn to the literature on birds, which are close relatives of the reptiles, but even that extensive literature permits few generalizations. The most recent reviews of the effects of environmental contaminants on amniote vertebrates (Stickel 1973; Stickel 1975) do not deal at length with reptiles, but they indicate that the following six generalizations may apply to reptiles, based on findings with other groups: (1) Even closely related species may differ considerably in their sensitivity to a given toxicant. Taxonomic affinity may have some predictive value, but only to a limited extent. Falconiform birds, for example, are generally sensitive to certain organochlorines, but different species may differ considerably in relative sensitivity. (2) Species at higher trophic levels tend to suffer most from persistent contaminants which cannot readily be detoxified or excreted. (3) The effects of contaminants vary considerably, depending on the physiological state of the animal. This is particularly true of fat soluble toxicants whose absorption and mobilization are strongly related to fat body cycling. (4) Metabolites of pesticides and other contaminants may be more or less toxic than the parent compound and more or less subject to storage. Toxicity thus depends on the form of the contaminant to which the animal is exposed. (5) Most contaminants appear to affect specific enzyme systems at the cellular level and thus would be expected to produce a variety of sublethal effects in different organisms. (6) Species with long life cycles are more likely to be affected by persistent contaminants than the short-lived species characteristic of unstable habitats.

Different classes of contaminants tend to have different sites of action in adversely affecting vertebrates. The organochlorine insecticides seem to inhibit active transport of cations and acutely toxic amounts probably act by inhibiting nervous transmission. Also, organochlorines may act subacutely to impair eggshell deposition in birds of certain groups. PCB's are known to inhibit reproduction in certain mammals. The exact mechanisms of these reproductive effects are poorly

known because of yet another effect produced by organochlorines. The enzymes induced to detoxify certain organochlorines are relatively nonspecific and may also deplete steroid hormones; such depletion may have a variety of effects on the organism's homeostatic balance. Rarely organochlorines have been shown to mimic the effects of estrogens. Organophosphate and carbamate insecticides act at the synapse, blocking nerve transmission by the inhibition of the enzyme acetylcholinesterase. Lethal action is thought to result from nerve blockage in the brain, but specific levels of inhibition are often difficult to relate to effects on the whole organism. Also, delayed neurotoxicity, a secondary phenomenon resulting from demyelination, has been attributed to certain organophosphates. Heavy metals may have various effects. More information on these phenomena can be found in the reviews cited above, in Matsumura (1975), and in Baron (1976).

Effects of Pesticide Applications on Reptiles

Reptiles have been killed by pesticides, usually as nontarget organisms receiving direct exposure to pesticides or by secondary poisoning resulting from the consumption of dead or moribund prey. Pesticides have been advocated as a means of snake control (Anon. 1957), but most large-scale mortality seems to have resulted from efforts directed at insects. In a recent article on control of vertebrate pests, Marsh and Howard (1978) reported that various organochlorines are toxic to reptiles and that DDT was formerly used successfully against snakes. The authors noted that no chemicals are presently registered for snake control, but that such control is often a "side benefit" of pesticides applied to houses and lawns for other purposes. Reptiles have been reported to be more sensitive to the effects of pesticides than are homeotherms, and reptilian mortality has been observed with dose levels that are generally safe for birds and mammals (Rudd and Genelly 1956). Such apparent sensitivity may result from the low metabolic rate of reptiles and their resultant inability to quickly detoxify contaminants. Reptiles are apparently less sensitive than fish, but are not directly comparable to them because fish are continuously exposed to dissolved toxicants in their exchange of respiratory gases and thus may passively accumulate some chemicals.

Much of the literature on observed effects on reptiles from pesticide usage (Table 1) dates from the early years of organochlorine use. More recent accounts of die-offs of reptiles are relatively rare, probably because the lethality of pesticides to reptiles is well known and such reports are no longer considered to be of scientific interest. Also, recent uses of pesticides have tended toward less hazardous types and generally more judicious applications.

Despite much evidence that organochlorine pesticides are toxic to reptiles, there have been few efforts to determine their acutely or chronically toxic levels. Logier (unpublished data) fed capsules with 0.01 g DDT to captive snakes and observed mortality in some individuals. Herald (1949) similarly reported both primary and secondary poisoning from DDT to reptiles. Indications that *Agkistrodon piscivorus* may be less sensitive to DDT than are various colubrid snakes were believed by Herald to be artifacts. Lizards (*Anolis*) were affected but not killed by eating dosed insects. Pond turtles (*Chrysemys*) seemed less sensitive than softshells (*Trionyx*) or mud turtles (*Kinosternon*). Surprisingly, there have been no more recent investigations of the toxicity of pesticides to reptiles other than those of Brock (1965), and Braverman (1979) who investigated the hazards to snakes of secondary poisoning by rodenticides. Reports on the symptoms of DDT intoxication in reptiles (Herald 1949; Logier, unpublished data) cite the tremors, loss of motor control, and paralysis that are characteristic of neurotoxicity. Similar behavioral effects were seen (Finley 1960) in a case of toxaphene poisoning.

DeWitt and George (1960) summarized numerous observations on reptiles in areas treated with heptachlor (2.2 kg per hectare; 2 lb per acre) for fire ant control. One set of observations recorded the disappearance of a marked population of *Agkistrodon piscivorus* together with the elimination of *Storeria* and *Natrix* (=*Nerodia*). Snakes of the genus *Thamnophis* persisted, but exhibited signs of poisoning. Observations on another area indicated that *Nerodia* were most affected and no ill effects were seen in *Thamnophis*, *Heterodon*, or *Agkistrodon* species. *Nerodia* are probably more thoroughly aquatic than the other species observed. Virtual elimination of aquatic turtles and reduction of populations of box turtles (*Terrapene carolina*) were reported. In a detailed account of the aforementioned studies, Matschke (1961) presented convincing evidence that widespread mortality affected the populations observed. Apparent widespread mortality of lizards (*Eumeces*, *Anolis*) was observed following one application.

Rosato and Ferguson (1968) fed endrin resistant mosquitofish to a variety of vertebrate species. The fish developed resistance to endrin in areas of heavy usage of the pesticide and they pose a considerable hazard to their predators. Four species of reptiles were killed by eating resistant fish which were found to contain upwards of 1,000 ppm of endrin in the tissues. On an approximate dosage basis, 2 mg/kg were

Table 1. *Effect of pesticide applications on reptiles.*

Pesticide	Application	Species	Effects	Authority
DDT	Not stated	*Thamnophis sirtalis* *Storeria occipitomaculata*	Some killed	Logier, unpubl. data
DDT	0.6 kg/ha (0.5 lb/acre)	Turtles	None	Couch (1946)
DDT	4.9 kg/ha (4.4 lb/acre)	*Opheodrys aestivus* *Sceloporus olivaceous*	Some killed	George and Stickel (1949)
DDT	2.2 kg/ha (2 lb/acre)	*Nerodia* sp. "Blacksnake"	Killed	Goodrum et al. (1949)
DDT	0.3-0.7 kg/ha (0.3-0.6 lb/acre)	9 spp. snakes 1 sp. turtle 1 sp. lizard 2 spp. turtles	Killed Killed "Sublethal effects"	Herald (1949)
DDT	1.1 kg/ha (1 lb/acre)	Water snakes	Killed	Hoffman and Surber (1949)
DDT	2.2 kg/ha (2 lb/acre)	*Terrapene carolina*	No effects on population	Stickel (1951)
DDT	0.2 kg/ha (0.2 lb/acre)	*Nerodia fasciata compressicauda*	Killed	Mills (1952)
DDT	In cage	*Agkistrodon piscivorous*	Killed	Munro (1949)
DDT and BHC	Up to 2.2 kg/ha (2 lb/acre)	*Malaclemys terrapin* *Terrapene carolina*	None	Springer (1961)
Dieldrin	Locally at tsetse breeding sites	2 spp. lizards	Killed	Koeman et al. (1971)
Dieldrin	Locally at tsetse breeding sites	10 spp. lizards 8 spp. snakes	Killed	Wilson (1972)
Dieldrin and Heptachlor	2.2 kg/ha (2 lb/acre)	*Nerodia erythrogaster* *Storeria dekayi*	Killed	Baker (1958)
Dieldrin and Heptachlor	2.2 kg/ha (2 lb/acre)	3 spp. snakes	Killed	DeWitt et al. (1960)
Endrin	Secondary intake	*Chrysemys scripta* *Nerodia erythrogaster* *N. rhombifera* *Agkistrodon piscivorus*	Killed	Rosato and Ferguson (1968)
Heptachlor	2.2 kg/ha (2 lb/acre)	*Nerodia* sp. *Agkistrodon piscivorus*	Killed	Glasgow (1958)
Heptachlor	2.2 kg/ha (2 lb/acre)	10 spp. snakes 2 spp. turtles	Some killed	DeWitt and George (1960); Matschke (1961)
Heptachlor	2.2 kg/ha (2 lb/acre)	2 spp. turtles 1 sp. lizard 5 spp. snakes	Killed	DeWitt et al. (1962)
Heptachlor	2.2 kg/ha (2 lb/acre)	*Chrysemys* sp.	Killed	Rosene et al. (1961)
Heptachlor	2.2 kg/ha (2 lb/acre)	2 spp. turtles 1 sp. lizard 4 spp. snakes	Killed	Ferguson (1963)
Heptachlor	2.2 kg/ha (2 lb/acre)	Turtles 2 spp. lizards 6 spp. snakes	Killed	Smith and Glasgow (1965)
Vapona	Topical	Snakes	None	Lentz and Hoessle (1971)

Table 1 (cont.)

Pesticide	Application	Species	Effects	Authority
Phosphamidon and Bidrin	1.1 kg/ha (1 lb/acre), 0.3 kg/ha (¼ lb/acre)	*Agkistrodon* spp. *Nerodia* spp.	None	Oliver (1964)
Six rodent poisons	Secondary intake	*Pituophis catenifer*	None	Brock (1965)
Strychnine Alkaloid	Secondary intake	*Pituophis catenifer*	Killed	Brock (1965)
Fluoroacetamide (1081)	Secondary intake	3 spp. snakes	None	Braverman (1979)
Toxaphene	2.2 kg/ha (2 lb/acre)	*Chrysemys picta* *Thamnophis sirtalis*	Killed Killed	Finley (1960)

required to kill the reptiles, whereas bird and fish species required an average of 9 and 13 mg/kg. Although dying on generally lower doses, the reptilian species always survived longer than the fish, amphibian, or avian species tested.

In most instances in which reptiles were reported to have survived or been killed by pesticide applications, there was no determination of the amount of toxicant that had actually reached the animals. Such reports are of limited value in producing replicable data, but they are of great practical value in assessing the hazards posed to reptiles by pesticide applications.

Kinetics of Contaminant Residues in Reptiles

Reports of residues found in dead and surviving reptiles (Table 2) have shown that these animals can accumulate contaminants in different tissues in greatly differing amounts. However, because a variety of species, different methods of analysis, and examination of different tissues have been used, few conclusions can be drawn concerning their significance. Improved technology has permitted increased accuracy in the detection and quantification of contaminant residues. These advances have often cast doubts on the accuracy of residue reports published before widespread application of the new methods. It was discovered, for example, that PCB's often interfere with quantification of DDT, DDD, or DDE (see Dustman et al. 1971). PCB's are nearly ubiquitous in wild animals and the failure of a report to mention PCB's may be cause for suspicion that PCB's are misreported as pesticide residues. PCB's and toxaphene are complex mixtures with components that are metabolized selectively by certain animals. Their quantification is difficult and has not been standardized; comparisons of PCB residues are risky and probably valid only when reports are from the same laboratory and when PCB's are extracted from similar tissues. Another problem may arise when laboratories experienced in measuring residues in water, soil, or plants err by underestimating the problems of extraction and cleanup of residues from animal tissues. All these factors may lead to erroneous residue reports. Residues are expressed on different bases (whole body or organ weights; wet weight, dry weight, lipid weight) and reports expressed in these different ways cannot be compared directly.

Organochlorines tend to accumulate in fat and large amounts of these materials may be safely stored by reptiles in the relatively isolated fat bodies. However, increased metabolism of fat may mobilize the residues, making them more available to other tissues. Fat may protect animals by partitioning insecticide residues, but the presence of fat in large amounts may actually enhance the storage of contaminants which might otherwise be detoxified or eliminated. Thus, although fat often has easily detected and quantified residues (Fleet et al. 1972; Lawler 1977; Stafford et al. 1976), their concentrations could be expected to vary greatly depending on the nutritional and reproductive state of the animal. Whole-body residues of contaminants may be more indicative, but these also depend on the amount of fat present, and percentage lipid probably should also be recorded to make such data more meaningful. Residues of other contaminants such as heavy metals also may be sequestered in inactive sites (for example, lead in bones) making residue levels difficult to interpret. The action of most organochlorine pesticides is probably in the brain; brain levels are diagnostic of death in some homeotherms, but the literature records no attempts to determine lethal levels in reptiles.

Several investigators have attempted to show the rates of uptake and loss of environmental contaminants in reptiles, or the distribution of these materials

Table 2. *Residues of environmental contaminants reported in dead and surviving reptiles.*

Authority	Species	Application (if reported)	Sample type; basis on which residues are expressed[a]	Contaminants (max. conc. in ppm)
DeWitt and George (1960)	Reptiles	2.2 kg/ha (2 lb/acre)	Whole body; dry weight	Heptachlor epoxide (6.6)
DeWitt et al. (1960)	3 spp. snakes	2.2 kg/ha (2 lb/acre)	Whole body; dry weight	Dieldrin (77.5) Heptachlor epoxide (11.3)
Finley (1960)	*Chrysemys picta*	2.2 kg/ha (2 lb/acre)	Whole body; dry weight	Toxaphene (154)
DeWitt et al. (1962)	Box turtle 8 spp. snakes	2.2 kg/ha (2 lb/acre)	Liver, heart, kidney, whole body; dry weight	Heptachlor epoxide (173.9)
Matschke (1961)	5 spp. snakes	2.2 kg/ha (2 lb/acre)	Whole body, liver, kidney; dry weight	Heptachlor epoxide (66)
	Terrapene carolina		Heart, liver, kidney; dry weight	Heptachlor epoxide (308)
Rosene et al. (1961)	Hognose snake Red-eared turtle	2.2 kg/ha (2 lb/acre)	Whole body; dry weight	Heptachlor epoxide (172—turtle)
Keith and Hunt (unpubl. data)	*Trionyx spinifer*	—	Fat; lipid weight "Flesh," wet weight Viscera; wet weight	DDE (700) DDT (32) DDE (8) DDT (0.43) DDE (12.5) DDT (3.7) Dieldrin (3.5) Heptachlor epoxide (1.1) Toxaphene (1.0)
Cully and Applegate (1967*a*)	3 spp. *Cnemidophorus*	—	Various tissues including fat; wet weight	BHC (11.5) Methyl parathion (4.2)[b] Parathion (4.1) DDE (45.9) DDD (34.8) DDT (44.3)
Cully and Applegate (1967*b*)	3 spp. *Cnemidophorus*	—	Muscle; wet weight	BHC (2.0) Methyl parathion (5.1) Parathion (4.6) DDE (7.0) DDD (6.0) DDT (4.7)
Meeks (1968)	3 spp. turtles 2 spp. snakes	0.2 kg/ha (0.2 lb/acre)	Various tissues including fat; dry weight	DDT (36.4)
Applegate (1970)	5 spp. lizards	—	Whole body; wet weight	Methyl parathion (0.7)[b] Parathion (0.1) DDE (1.69) DDD (1.50) DDT (1.50)
Korschgen (1970)	*Thamnophis sirtalis* *Pituophis sayi*	25.1 kg/ha (22.4 lb/acre) total over 17 years	Whole body; wet weight	Aldrin (0) Dieldrin (14.40) DDT (0.48)
Koeman et al. (1971)	*Agama agama* *Panaspis dahomeyense*	Local applications	Whole body; wet weight	Dieldrin (0.83) DDE (< 0.05)

Table 2. (cont.)

Authority	Species	Application (if reported)	Sample type; basis on which residues are expressed[a]	Contaminants (max. conc. in ppm)
Laubscher et al. (1971)	*Pituophis melanoleucus*	—	Liver, fat; wet weight	DDE (8.5) DDD (0.047) DDT (1.6) Dieldrin (0.057)
Devine and Wilcox (1972)	*Nerodia sipedon*	1.1 kg/ha (1 lb/acre)	Whole body; wet weight	Trichlorfon (< 0.05) DDVP (< 0.05)
Dustman et al. (1972)	*Thamnophis sirtalis*	—	Carcass; liver; wet weight	Mercury (0.60)
Fleet et al. (1972)	12 spp. snakes	—	Fat; lipid weight	DDE (1009.4) DDD (7.3) DDT (38.5) Dieldrin (13.8)
Ogden et al. (1973)	American alligator (*Alligator mississippiensis*) American crocodile (*Crocodylus acutus*)	—	Eggs; wet weight	DDE (3.23) DDD (0.16) DDT (0.59) Dieldrin (0.053) PCB (0.40) Arsenic (0.2) Mercury (0.71) Cadmium (0.05) Zinc (11) Lead (0.5) Copper (15)
Snyder et al. (1973)	*Sceloporus clarki* *S. jarrovi*	—	Whole body; wet weight	DDE (0.01)
Brisbin et al. (1974)	19 spp. snakes	—	Whole body; wet weight	Radiocesium (1032.6 pCi/g)
Hillestad et al. (1974)	*Caretta caretta*	—	Tissue samples; wet weight eggs; wet weight	DDTR (0.30) Dieldrin (0.06) Mercury (0.09) Zinc (32) Cadmium (0.56) Copper (6) Lead (12)
Thompson et al. (1974)	*Chelonia mydas*	—	Eggs; wet weight	DDE (0.009) PCB (0.22)
Vermeer et al. (1974)	*Caiman sclerops*	13 pesticides in variable amounts	Brain, liver; wet weight	DDT (< 0.01) Dieldrin (< 0.01) Endrin (< 0.01) Pentachlorophenol (0.24) Mercury (0.41)
Bauerle et al. (1975)	*Pituophis catenifer*	—	Fat (for organochlorines); lipid weight Liver (for lead)	DDE (1.06) DDT (0.05) Dieldrin (0.04) Oxychlordane (< 0.01) Heptachlor epoxide (< 0.02) α-BHC (0.01) β-BHC (0.013) PCB (0) Lead (0.659)

Table 2. (cont.)

Authority	Species	Application (if reported)	Sample type; basis on which residues are expressed[a]	Contaminants (max. conc. in ppm)
Dimond et al. (1975)	*Thamnophis sirtalis*	1.1 kg/ha (1 lb/acre)	Whole body; wet weight	DDT (3.20)
Janssen et al. (1976)	Aquatic snakes	—	Fat; lipid weight	DDE (31.6) DDD (3.9) DDT (4.7) Dieldrin (0.9)
Reeves et al. (1977)	4 spp. turtles	Multiple applications	Whole body; (minus shell) wet weight	DDE (3.81) DDD (0.08) DDT (0.07) Dieldrin (0.01) Endrin (0.01)
Woodham et al. (1977)	Lizards, snakes	8 pesticides, multiple applications	Whole body; wet weight	Ethyl parathion (0.01) β-BHC (0.02) Heptachlor epoxide (0.01) Dieldrin (0.04) DDTR (57.85)
Lawler (1977)	*Drymarchon corais*	—	Fat; lipid weight	Dieldrin (13.3) Heptachlor epoxide (4.02) *trans*-nonachlor (2.42) Octachlor epoxide (=oxychlordane) (2.39) Mirex (17.20) PCB (12.3)
Rolfe et al. (1977)	*Thamnophis sirtalis* *T. radix*	—	Whole body; dry weight	Lead (9.6) Lead (69.7)
Stafford et al. (1976)	*Nerodia* spp. *Agkistrodon* spp.	—	Fat; lipid weight	DDE (1,161.2) PCB (123.3)
Fleet and Plapp (1978)	10 spp. snakes	—	Fat; lipid weight	DDE (596.6) DDT (14.6)
Hall et al. (1979)	*Crocodylus acutus*	—	Eggs; wet weight	DDE (2.9) DDD (0.07) DDT (0.23) Dieldrin (0.03) Heptachlor epoxide (0.04) Oxychlordane (0.07) *cis*-chlordane (0.01) *trans*-nonachlor (0.04) *cis*-nonachlor (0.03) Mirex (0.02) PCB (1.4)
Holcomb and Parker (1979)	*Chrysemys scripta*	8.4 kg/ha (7.5 lb/acre) total of 4 applications	Liver; dry weight Eggs; dry weight	Mirex (2.1) Mirex (2.2)
	Terrapene carolina	8.4 kg/ha (7.5 lb/acre) total of 4 applications	Liver; dry weight Eggs; dry weight	Mirex (4.1) Mirex (2.5)
Punzo et al. (1979)	4 spp. snakes	—	Fat; lipid weight	DDE (0.22) Dieldrin (0.13) Heptachlor epoxide (0.05)

Table 2. (cont.)

Authority	Species	Application (if reported)	Sample type; basis on which residues are expressed[a]	Contaminants (max. conc. in ppm)
Punzo et al. (1979)	2 spp. turtles	—	Fat; lipid weight	DDE (0.02) Dieldrin (0.07)
	9 spp. lizards	—	Carcass or viscera	DDE (0.25) Dieldrin (0.01)
	Snake eggs (3 spp.)	—	Wet weight	DDE (0.06) Dieldrin (0.05) Heptachlor epoxide (0.04)
	Turtle eggs (1 sp.)	—	Wet weight	DDE, Dieldrin, Heptachlor epoxide not detected

[a]Whole body wet weights yield the lowest apparent levels, relative to organochlorine residue loads. When expressed on a dry weight basis, the same loads will yield apparent levels about 4 times as great. When expressed on the basis of lipid weight, the levels reported are usually many times those based on the actual body weight.
[b]Most other investigators have been unable to confirm residues of parathion and methyl parathion.

among various tissues. Meeks (1968) reported DDT residues in several species of reptiles inhabiting a marsh that had been treated with 0.2 kg per hectare (0.2 lb per acre). In *Chelydra serpentina*, *Emydoidea blandingi*, and *Chrysemys picta*, the highest levels (up to 16.5 ppm) were found in fat. The liver contained the next highest residues (up to 2.7 ppm). The highest brain residue level found was 1.2 ppm which evidently was below the lethal level for *E. blandingi*. Fat residues up to 36.4 ppm were found in *Nerodia sipedon* and one of these water snakes had a brain residue level of 11 ppm. Kidney residue levels in this species and *Elaphe vulpina* were high (up to 7.3 ppm) and tended to exceed liver levels. The residue levels reported in reptiles exceeded those in the birds, mammals, and fish tested.

Owen and Wells (1976) fed captive turtles DDT, sacrified them at various times and assayed brain, liver, and fat for residues. In both *Chrysemys scripta* and *C. picta*, there was little significant accumulation in the first 24 h. In turtles dosed weekly for 3 weeks, there was significant accumulation in fat, but also a large concentration of DDD in the brain (17.19 ppm) was reported in *C. scripta*. Total residues in fat (97.9 ppm in *C. scripta*) were largely in the form of DDT and DDD.

Cully and Applegate (1976*a*, 1976*b*) analyzed for various pesticide residues in three species of *Cnemidophorus* and noted a decline from June to August. They attributed this loss to egg laying; pesticide residues were removed from the females when eggs were laid. This was supported by the finding that eggs contained five times the residue levels of adult females.

Fleet and Plapp (1978) showed a decline in residues of DDE and DDT after a 3-year period following cessation of DDT application. The loss rate was slow (a 50% decline in 3 years) and there was a general increase in the amount of DDE relative to DDT.

Holcomb and Parker (1979) showed that mirex residues in two turtle species declined almost continuously over an 8-year period. Hall et al. (1979) compared residues of organochlorines in crocodile eggs collected in 1977-78 with residues recorded 5 years earlier. They noted significant declines in DDD and DDT, but no significant decrease in the amounts of DDE or dieldrin.

Pearson et al. (1973) injected *Chrysemys scripta* adults with 20 mg/kg of dieldrin in a single dosing and analyzed tissues from animals sacrificed at various intervals after dosing. They found the highest concentrations (up to 1,329 ppm) in fat 70 days after dosing. Liver and most other tissues also increased in residue levels continuously over the 70-day test period. Brain levels reached nearly 27 ppm without reported ill effects. Part of the concentration reported in tissues apparently resulted from starvation during the test.

Robinson and Wells (1975) orally dosed *Trionyx spinifer* with 2 mg of cadmium acetate per animal. They found apparent concentration in the liver and kidney. However, their data indicate that part of the dose remained in the gut and absorption was not complete in the 96-h duration of the test.

The studies by Owen and Wells (1976) and Pearson et al. (1973) cited above may be somewhat diminished in value by indications that the animals used had significant prior exposure to organochlorine pesticides. Similarly, the turtles used by Robinson and Wells (1975) had a history of exposure to high levels of heavy metals.

Table 3. *Residues in animals thought to have been killed by pesticides.*

Species	Chemical	Mean residue level (ppm)	Reporting basis	Authority
Storeria dekayi	Dieldrin	77.5	Whole body, dry weight	DeWitt et al. (1960)
Panaspis dayhomeyense	Dieldrin	0.83	Whole body, wet weight	Koeman et al. (1971)
Nerodia sp.	Heptachlor epoxide	11.3	Whole body, dry weight	DeWitt et al. (1960)
Heterodon sp.	Heptachlor epoxide	4.2	Whole body, dry weight	DeWitt et al. (1960)
Agkistrodon piscivorus	Heptachlor epoxide	13.2	Whole body, dry weight	Matschke (1961)
Nerodia erythrogaster	Heptachlor epoxide	24.6	Whole body, dry weight	Matschke (1961)
Nerodia rhombifera	Heptachlor epoxide	18.5	Liver, dry weight	Matschke (1961)
Lampropeltis getulus	Heptachlor epoxide	54.0	Liver, dry weight	Matschke (1961)
Thamnophis sauritus	Heptachlor epoxide	18.1	Whole body, dry weight	Matschke (1961)
Thamnophis sauritus	Heptachlor epoxide	4.6	Whole body, dry weight	DeWitt et al. (1962)
Masticophis flagellum	Heptachlor epoxide	4.6	Whole body, dry weight	DeWitt et al. (1962)
Nerodia sp.	Heptachlor epoxide	11.7	Whole body, dry weight	DeWitt et al. (1962)
Chrysemys sp.	Heptachlor epoxide	2.2	Whole body, dry weight	DeWitt et al. (1962)
Lizard sp.	Heptachlor epoxide	5.0	Whole body, dry weight	DeWitt et al. (1962)
Chrysemys sp.	Heptachlor epoxide	172.0	Whole body, dry weight	Rosene et al. (1961)
Chrysemys picta	Toxaphene	154.0	Whole body, dry weight	Finley (1960)

Correlation of Residues With Lethality

The few instances in which mortality of reptiles can be related to specific residue levels have resulted from test sprayings, mostly conducted in the early 1960's (Table 3). Variation and sources of error in the reported residues include the possibility that the animal may not have died as a direct result of pesticide poisoning. Also, it is probable that an individual could assimilate far more than a lethal dose of a pesticide before its toxic effects are felt.

Matschke (1961), working in an area treated with heptachlor, collected for chemical analysis specimens killed by the pesticide. He was also able to collect surviving individuals of *Thamnophis sauritus*. Two survivors contained whole-body residues of heptachlor epoxide of 5.9 and 7.9 ppm (dry weight) and two killed individuals had 17.6 and 18.5 ppm. Various tissues of box turtles contained from 24 to 308 ppm (dry weight) heptachlor epoxide. Only turtles surviving the spray were reported because none of the numerous individuals killed by the spray was recovered in suitable condition for analysis.

The report by Lawler (1977) exemplifies the problems of diagnosing deaths of individuals as contaminant-related. Fat samples from eastern indigo snakes (*Drymarchon corais*) which had died in captivity in the Atlanta Zoo had residues of a number of pesticides in varying amounts. Because of the variables affecting storage of residues in fat and the lack of comparative evidence on mortality, little can be said about the relations of these residues to the condition of the snakes. One male had 13.3 ppm dieldrin, but this is close to the amount reported by Fleet et al. (1972) in apparently healthy water snakes. Also, it is possible that the residues in the indigo snake had been concentrated as a result of emaciation.

Sublethal Effects of Contaminants on Reptiles

Fleet et al. (1972) sampled snakes from two areas in Texas, one with a long history of pesticide use and the other relatively free of pesticide applications. They found high residues in snakes from the heavy application area and a statistically different species composition between the two areas. Oviparous species were nearly absent from the high-residue area, possibly resulting from interferences with reproduction similar to those seen in certain birds. This phenomenon has not been investigated in more detail. However, when Fleet and Plapp (1978) resampled the area 3 years later, they found a decrease in DDT residues and an apparent increase in the proportion of egg-laying species.

Phillips and Wells (1974) and Wells et al. (1974) reported on the effects of organochlorine insecticides on adenosine triphosphatase activity in various species of turtles. Using in vitro methods, they dosed excised tissues with three levels of pesticide and assayed for total Na^+-, K^+-, and Mg^{2+}-dependent ATPases. Phillips and Wells (1974) found these systems to be affected by DDT; however, at the lowest dose level the effect was stimulatory. Results were generally similar for the five species (*Graptemys geographica*, *Chelydra serpentina*, *Trionyx spinifer*, *Chrysemys scripta*, and *C. picta*) tested. Wells et al. (1974) used various tissues of *Graptemys geographica* to investigate the effects of aldrin and dieldrin on the

same enzyme systems. They found inhibition at all three dose levels chosen and observed greater effects from dieldrin than from aldrin. Neither study used brain tissue in assays although it is the presumed primary site of action by the pesticide.

Stafford et al. (1976) noted the differences in species composition and residue levels reported by Fleet et al. (1972) and attempted to explain these differences by interspecific differences in detoxifying mechanisms. The enzyme systems thought to function in pesticide metabolism were NADPH microsomal oxidase which acts on organochlorines, and glutathione-dependent alkyltransferase, which acts on organophosphate insecticides. For assays, the breakdown of radioactively labelled testosterone and fenitrothion was measured. They found that *Agkistrodon* spp. had greater NADPH microsomal oxidase activity in the liver than did species of *Nerodia*, apparently explaining the lower residue levels in *Agkistrodon* from the same habitats as *Nerodia*. Alkyltransferase activities were also higher in *A. piscivorus*, but were relatively lower in *A. contortrix*. Low activities of both enzymes in *N. rhombifera* were suggested to account for its absence from high-residue areas. The authors concluded that microsomal oxidase activity is more closely correlated with residues and distribution patterns than is alkyltransferase.

Stickel (1951) studied the effects of an annual aerial application of DDT (2.2 kg per hectare; 2 lb per acre) on survival and growth in a natural population of box turtles. No significant effects on growth or survival were found, suggesting that a variety of physiological mechanisms were functioning normally.

Needs for Future Research

Research on the effects of environmental contaminants on reptiles should proceed on several fronts. A series of experiments should examine whether certain contaminants have sublethal effects of possibly great consequence in nature, as have been seen in other kinds of vertebrates. Behavioral and reproductive studies could be carried out on relatively small captive populations, following the protocols that have already been well tested. Both lethal and sublethal effects are strongly related to the kinetics of the contaminants in reptiles and a second line of research should investigate this aspect of the problem. Reptiles are active and predatory for the most part, yet they are metabolically less able than homeotherms, suggesting that reptiles' uptake and loss patterns of contaminants would differ greatly from those of homeotherms. Kinetic studies would not only be of intrinsic interest, but they might also help in the interpretation of the residue data that have accumulated.

Work on levels of cholinesterase inhibition that are diagnostic of lethal exposure to organophosphate and carbamate pesticides is proceeding in other kinds of vertebrates and should be pursued in reptiles. Comparative studies of fish, birds, and mammals (e.g., Murphy et al. 1968) have shown remarkable differences in sensitivity to different organophosphorus insecticides. Other studies (Andersen et al. 1977) have shown amphibians to be many times less sensitive to most organophosphates than other groups tested. Surprisingly, no information on reptilian sensitivity to these chemicals is available. Some studies on the effects of certain cholinesterase inhibitors on reptiles are under way at Patuxent Wildlife Research Center, but additional work is necessary.

Reptiles offer certain advantages for physiological study (Pearson et al. 1973), and it is likely that studies with reptilian subjects to investigate the mode of action of pesticides will continue. Although usually undertaken with other goals, such studies might lead to information of significance to reptilian biologists concerned with contaminants in the field.

Petroleum hydrocarbons, either leaking slowly from permanent sources or catastrophically from accidental spills, may threaten aquatic or marine reptiles. Mortality of sea turtles (*Chelonia* and *Lepidochelys*) has been associated with the IXTOC I oil spill (Patuxent Wildlife Research Center, unpublished data). Also, there is some fear that sea turtle nests may be contaminated with oil and that the eggs may be as vulnerable to tiny amounts of oil as are bird eggs.

Synthetic pyrethroids are a new class of insecticide that may be widely used in the future. They are said to be highly toxic and more persistent than organophosphates. Their effects on reptiles are unknown.

Closer attention to contaminant-produced episodes involving reptiles would help to identify sensitive species and particularly hazardous chemicals. Further, this attention would suggest research that might lead to conclusions of specific or general applicability. As for threatened or endangered species, special attention should be devoted to determine whether pollutants might be contributing to the status of their populations. When working with threatened or endangered species which are not available for experimental verification of suspected contaminant problems, certain experimental subjects might have high potential for predictive value. For example, experiments on the American alligator (*Alligator mississippiensis*) might be of great value in dealing with contaminants in the many endangered species of crocodilians.

In summary, the efforts devoted to contaminant effects on birds, mammals, and aquatic organisms should be duplicated on reptilian subjects. Such efforts might not only protect reptilian populations, but also might benefit populations of other kinds of verte-

brates because reptiles might strongly show effects which are expressed only subtly in birds and mammals.

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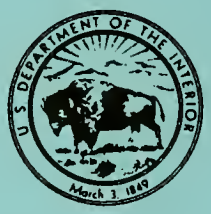

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